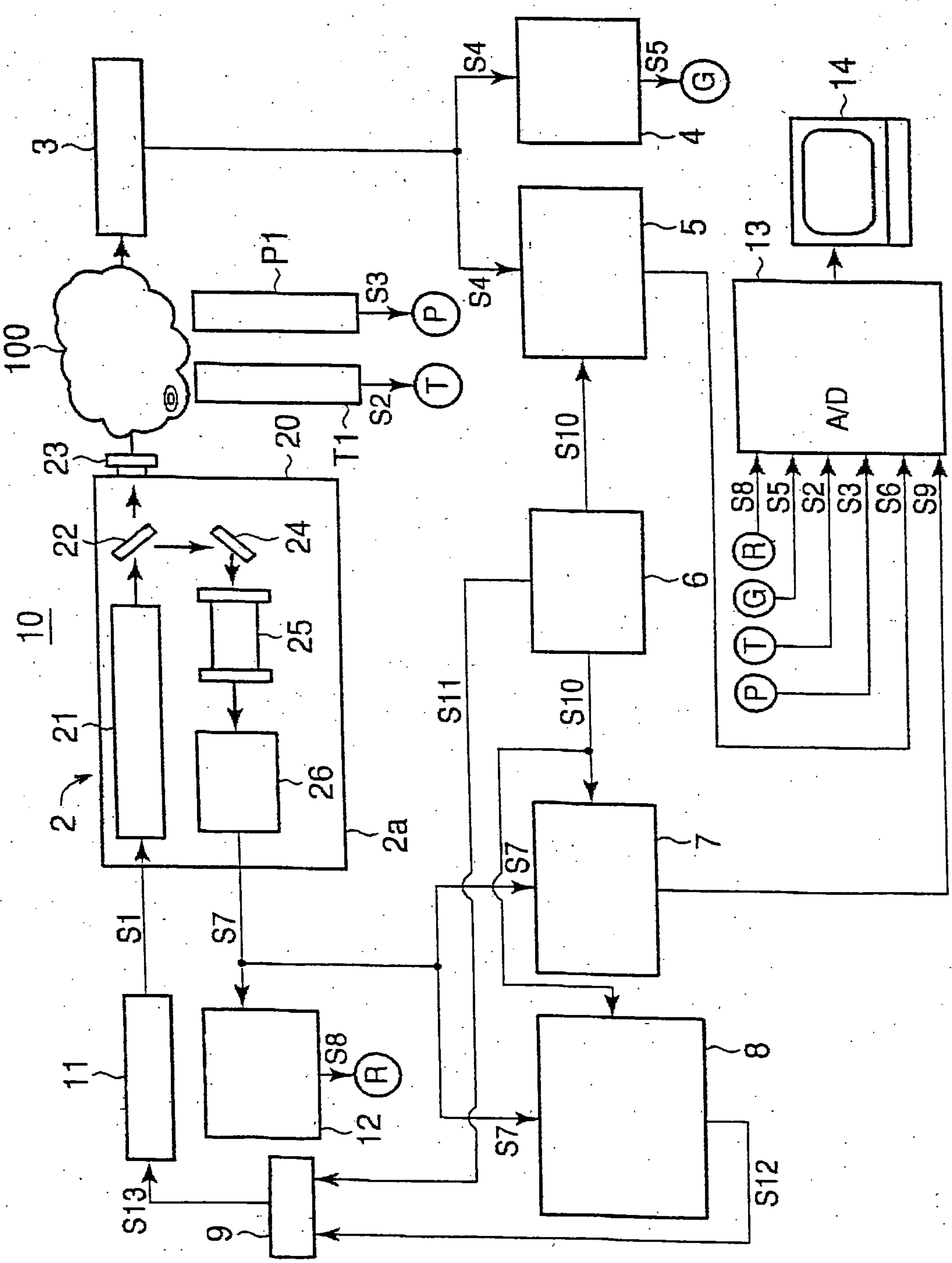
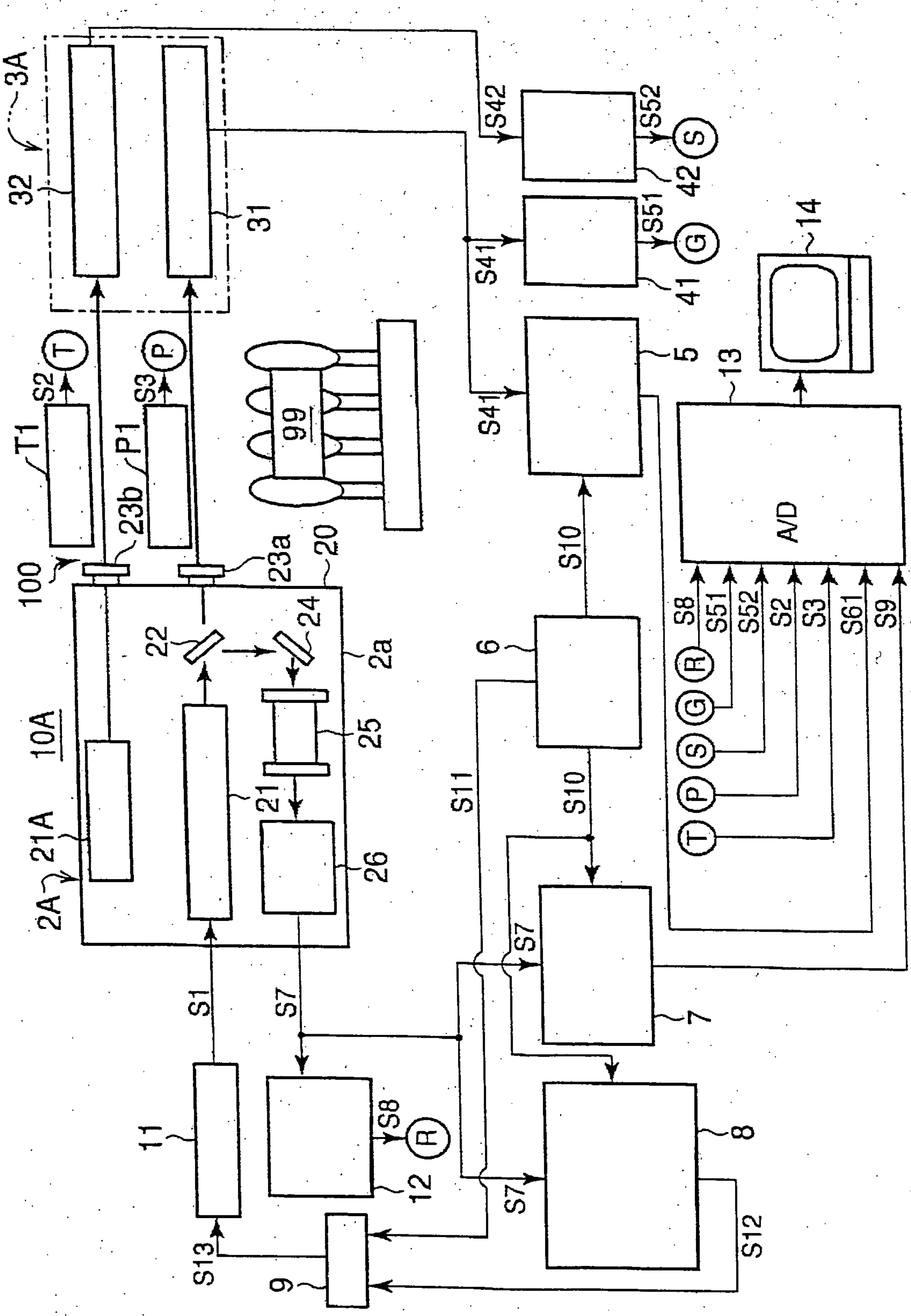
FIG. 1



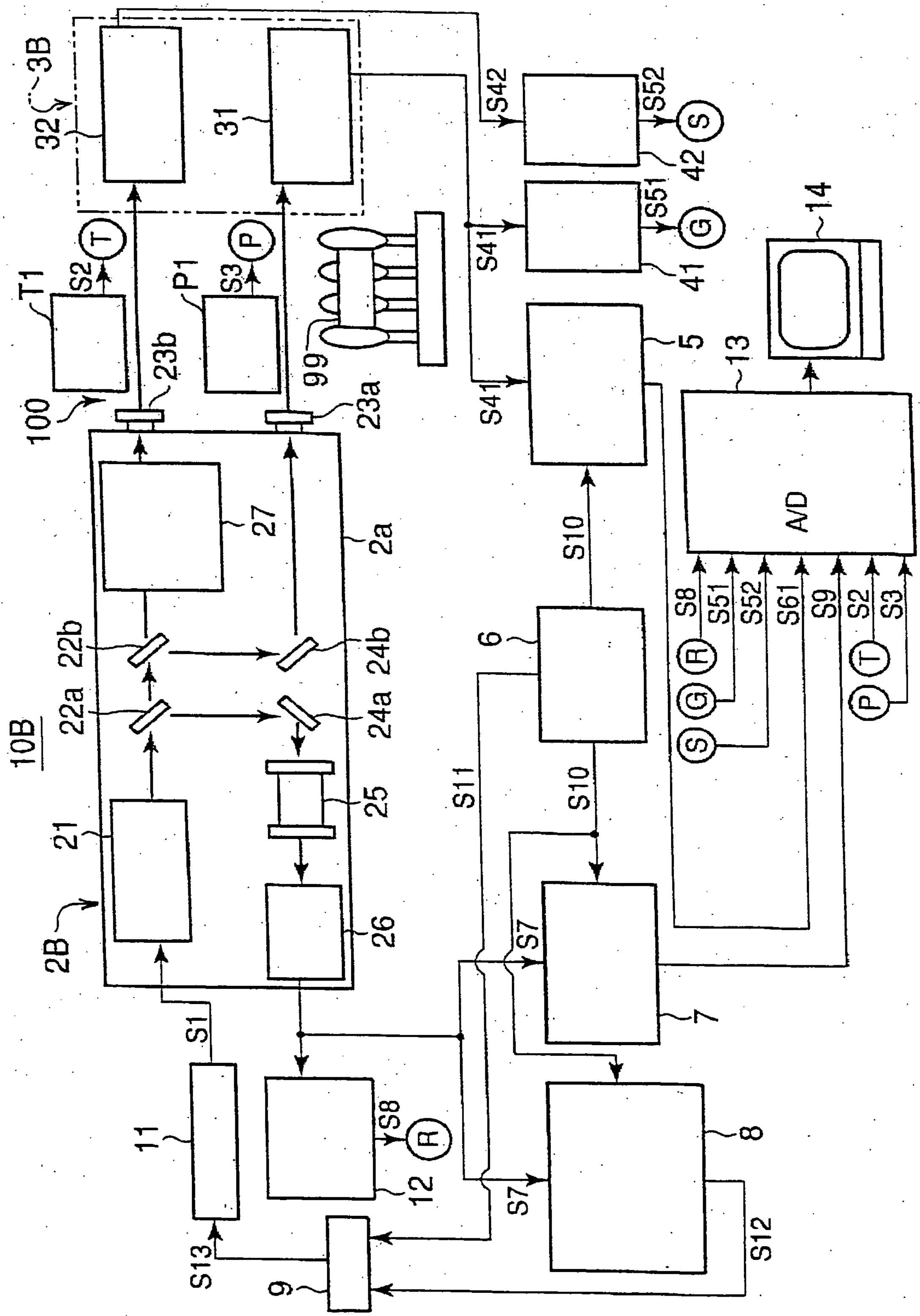
10
2
2a
20
21
22
23
24
25
26
100
3
4
5
6
7
8
9
11
12
13
14
P1
T1
A/D
S1
S2
S3
S4
S5
S6
S7
S8
S9
S10
S11
S12
S13
P
T
G
R

FIG. 2



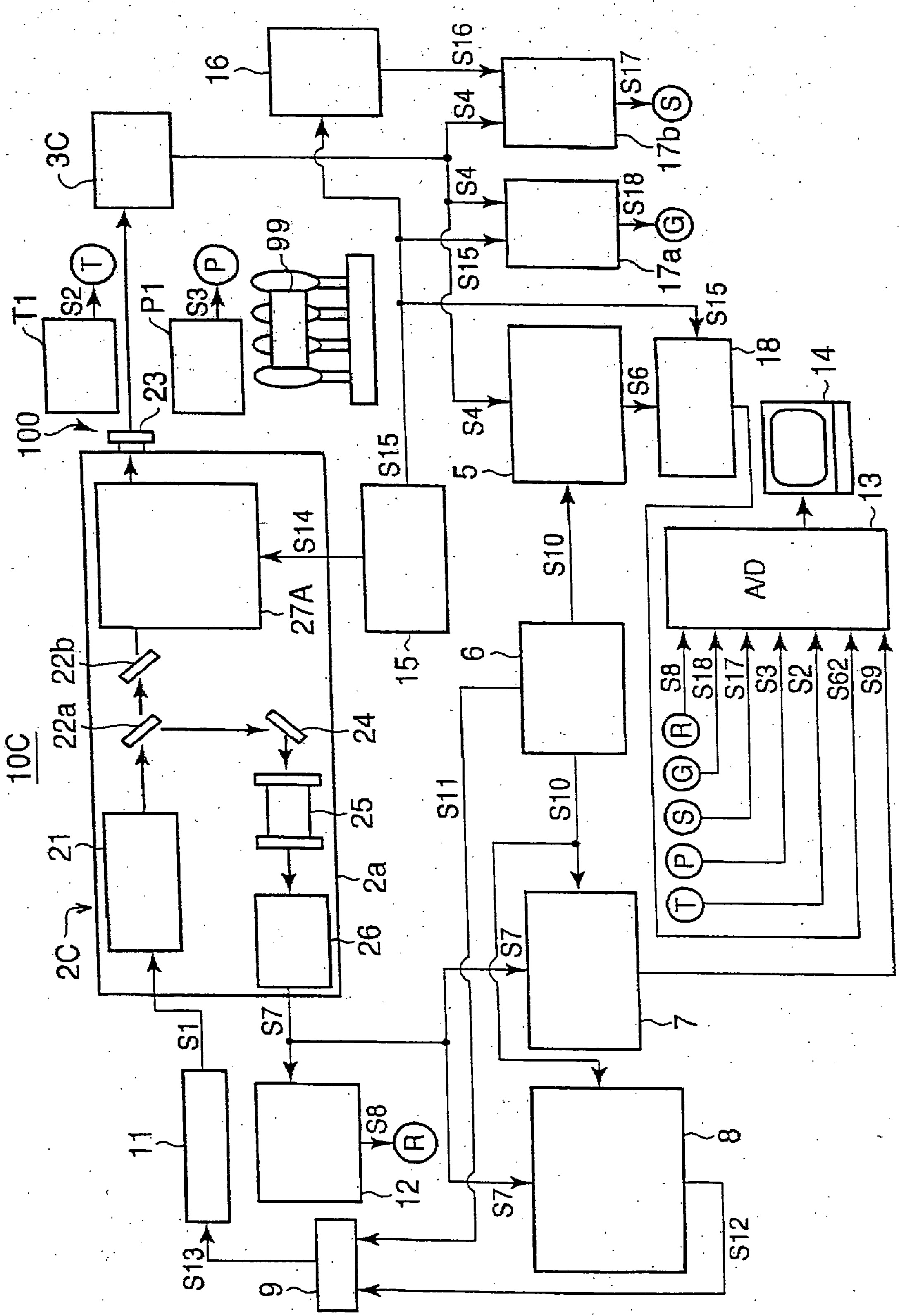
3A
32
31
T1
P1
S2
S3
T
P
100
23b
23a
20
99
S42
S52
S
42
S41
S51
G
41
5
14
13
A/D
10A
21A
2A
22
24
2a
25
21
26
6
S10
S11
S8
S51
S52
S2
S3
S61
S9
R
7
S7
S1
11
12
8
9
S13
S12

FIG. 3



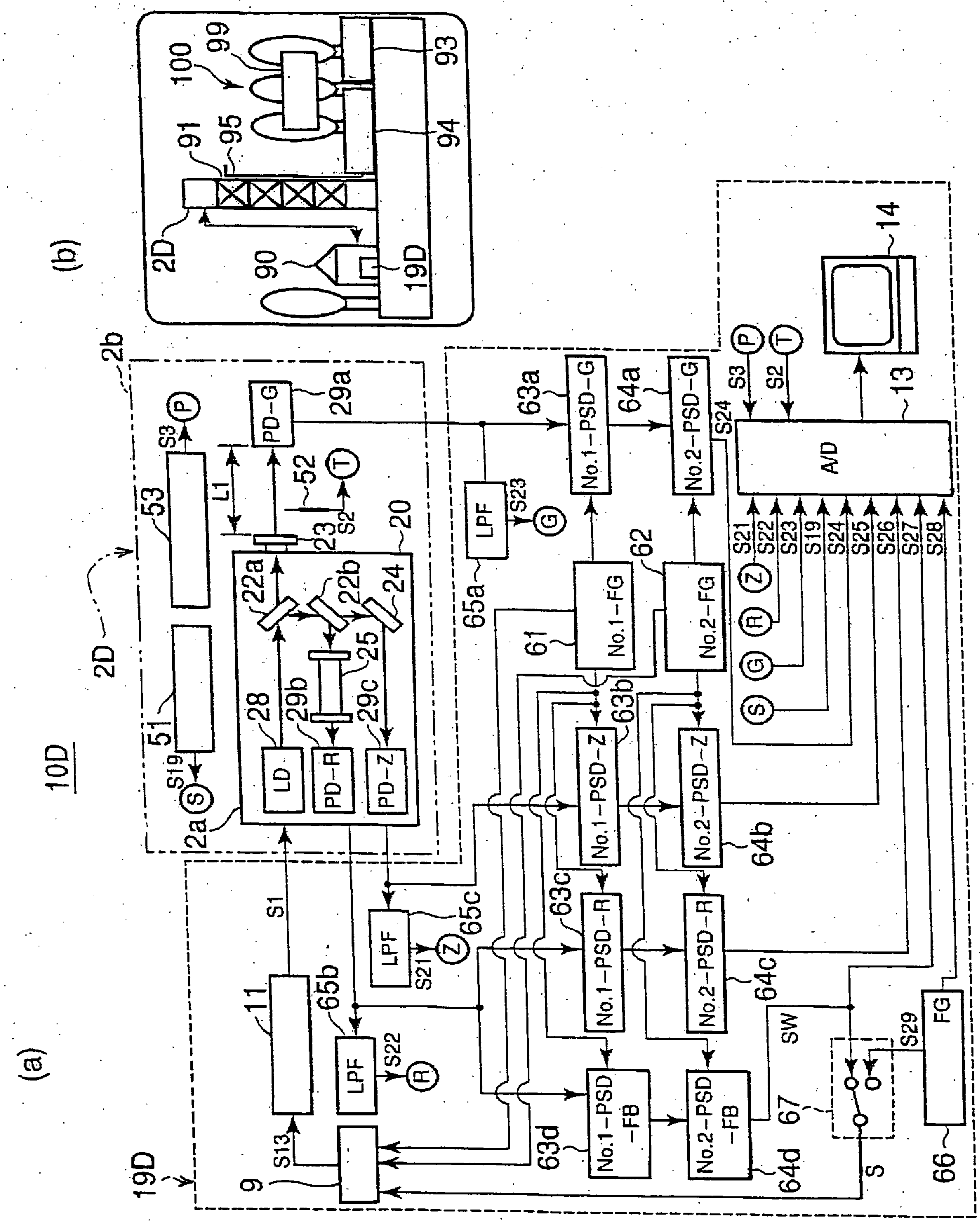
10B
2B
21
22a
22b
24a
24b
25
26
27
2a
23a
23b
100
T1
S2
T
P1
S3
P
32
3B
31
99
S42
S52
S
42
S41
S51
G
41
5
14
13
A/D
S10
6
S11
S7
7
8
S12
9
S13
S1
11
12
S8
R
S61
S9

FIG. 4



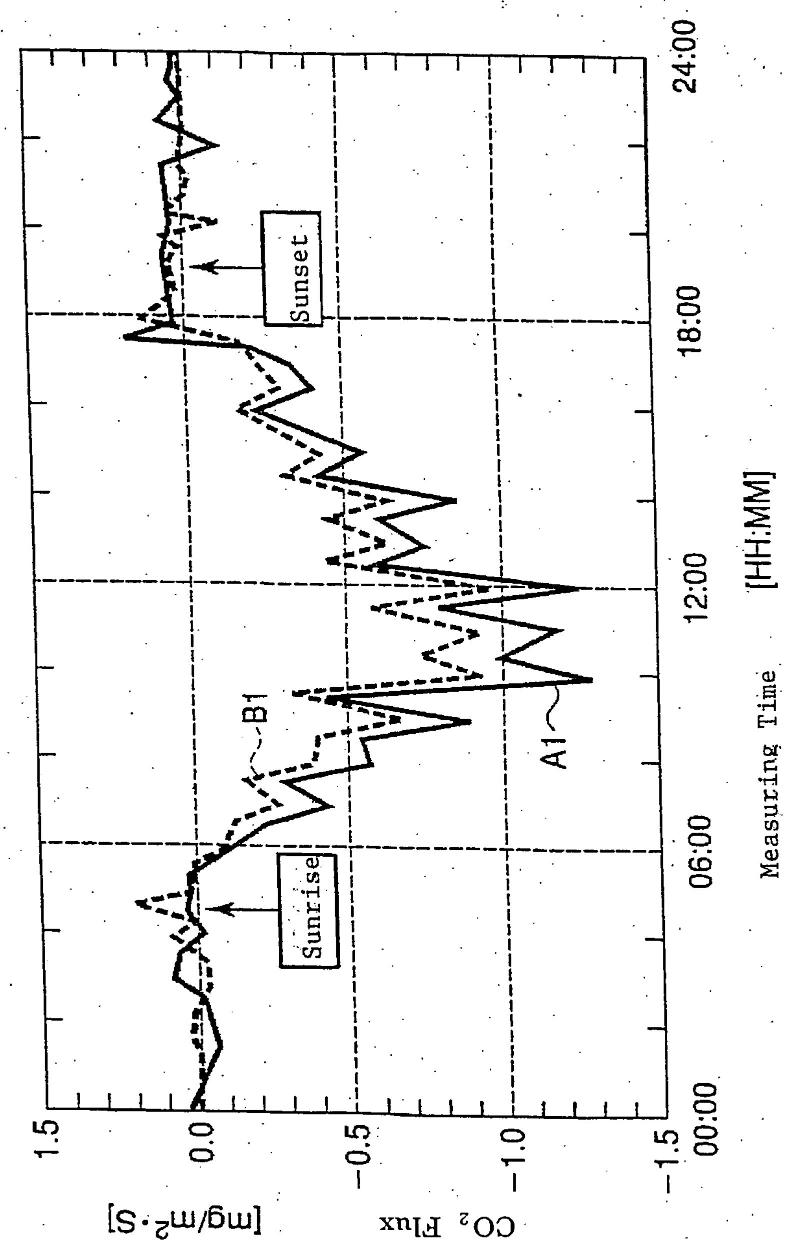
10C
2C
2a
21
22a
22b
23
24
25
26
27A
100
T1
S2
T
P1
S3
P
99
3C
16
S16
S17
S
17b
S4
S18
G
17a
S15
5
S6
18
14
13
A/D
S14
15
S10
6
S11
7
S7
8
S12
9
S13
11
12
S8
R
S1
S62
S9

FIG. 5



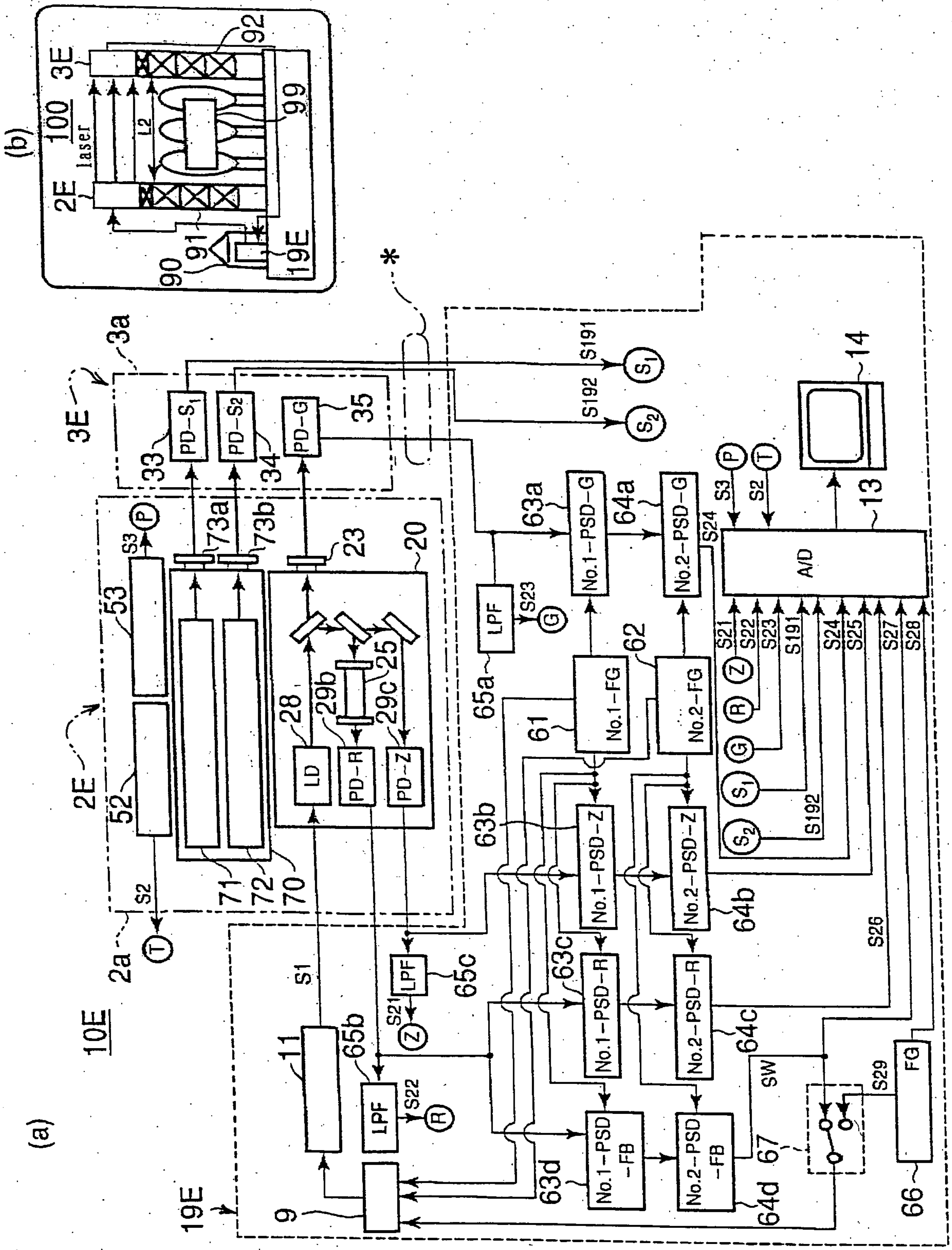
(a)
(b)
10D
2D
2a
2b
19D
LD
PD−R
PD−Z
PD−G
28
29a
29b
29c
22a
22b
24
25
23
20
51
52
53
L1
S1
S2
S3
S13
S19
S21
S22
S23
S24
S25
S26
S27
S28
S29
LPF
65a
65b
65c
No.1−FG
No.2−FG
61
62
No.1−PSD−G
No.2−PSD−G
No.1−PSD−Z
No.2−PSD−Z
No.1−PSD−R
No.2−PSD−R
No.1−PSD −FB
No.2−PSD −FB
63a
63b
63c
63d
64a
64b
64c
64d
A/D
13
14
FG
66
67
SW
S
9
11
90
91
93
94
95
99
100

FIG. 6



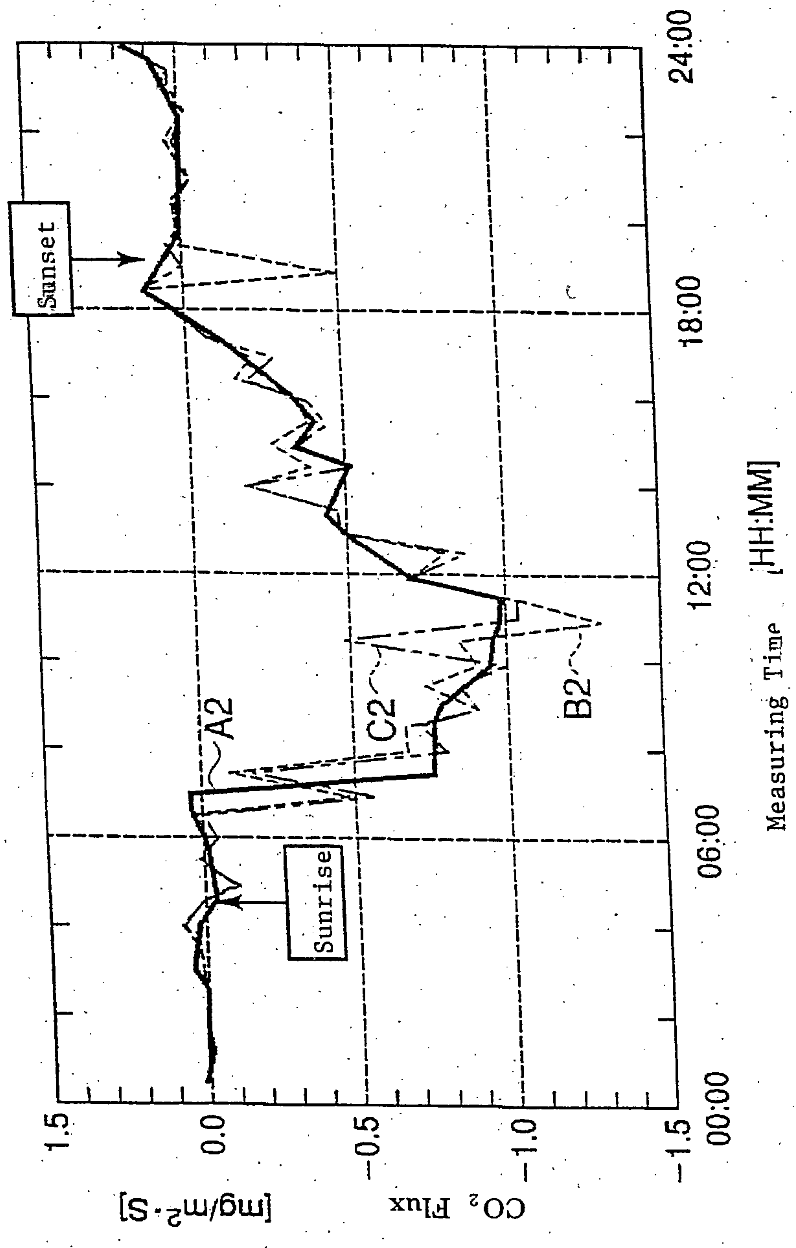
1.5
0.0
−0.5
−1.0
−1.5
CO_2 Flux
[mg/m²·S]
00:00
06:00
12:00
18:00
24:00
Measuring Time
[HH:MM]
Sunrise
Sunset
A1
B1

FIG. 7



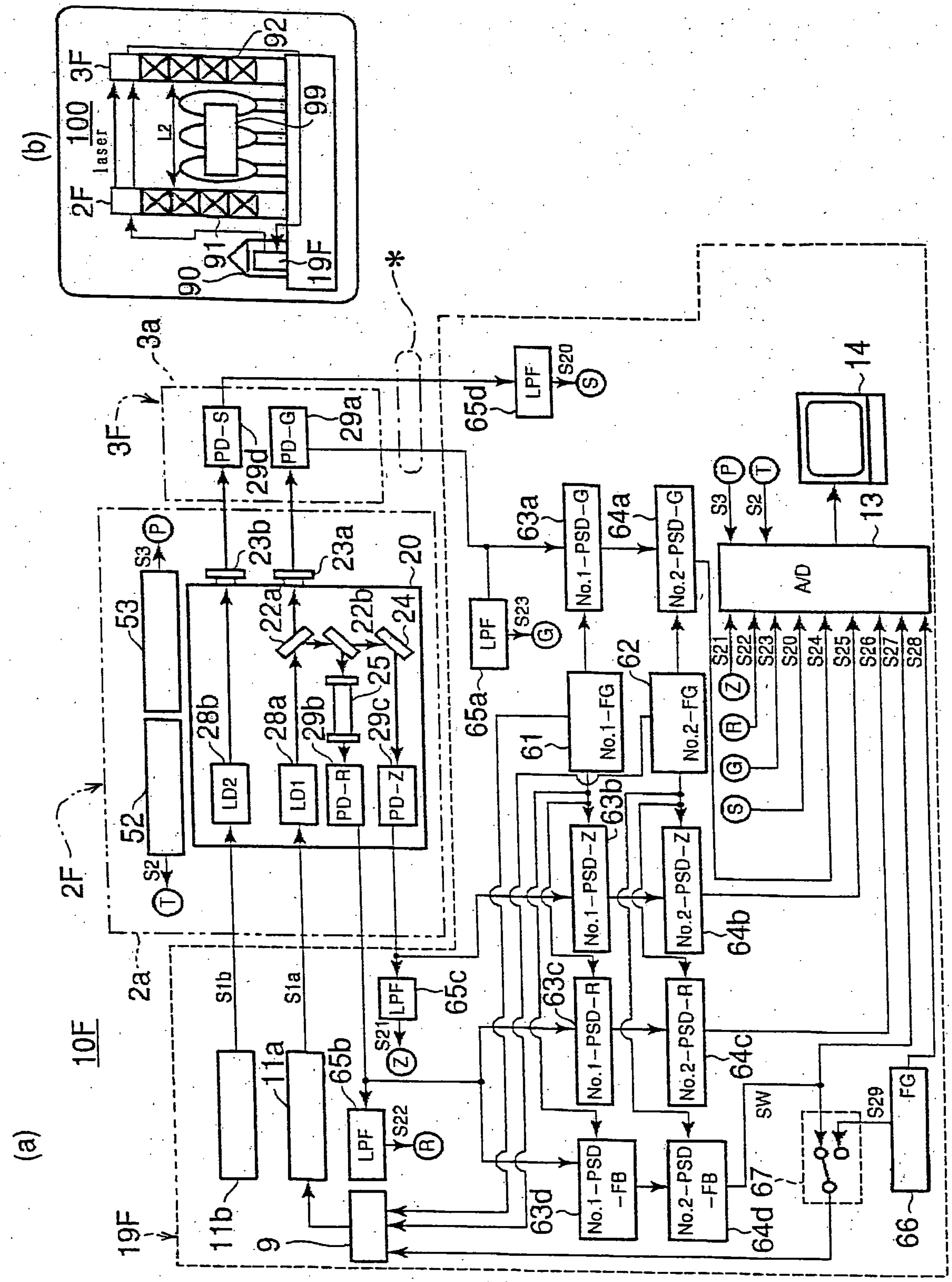
(a)
(b)
10E
100
laser
L2
2E
3E
2a
3a
19E
PD-S1
PD-S2
PD-G
LD
PD-R
PD-Z
LPF
No.1-FG
No.2-FG
No.1-PSD-G
No.2-PSD-G
No.1-PSD-Z
No.2-PSD-Z
No.1-PSD-R
No.2-PSD-R
No.1-PSD -FB
No.2-PSD -FB
FG
A/D
SW
S1
S2
S3
S21
S22
S23
S24
S25
S26
S27
S28
S29
S191
S192

FIG. 8



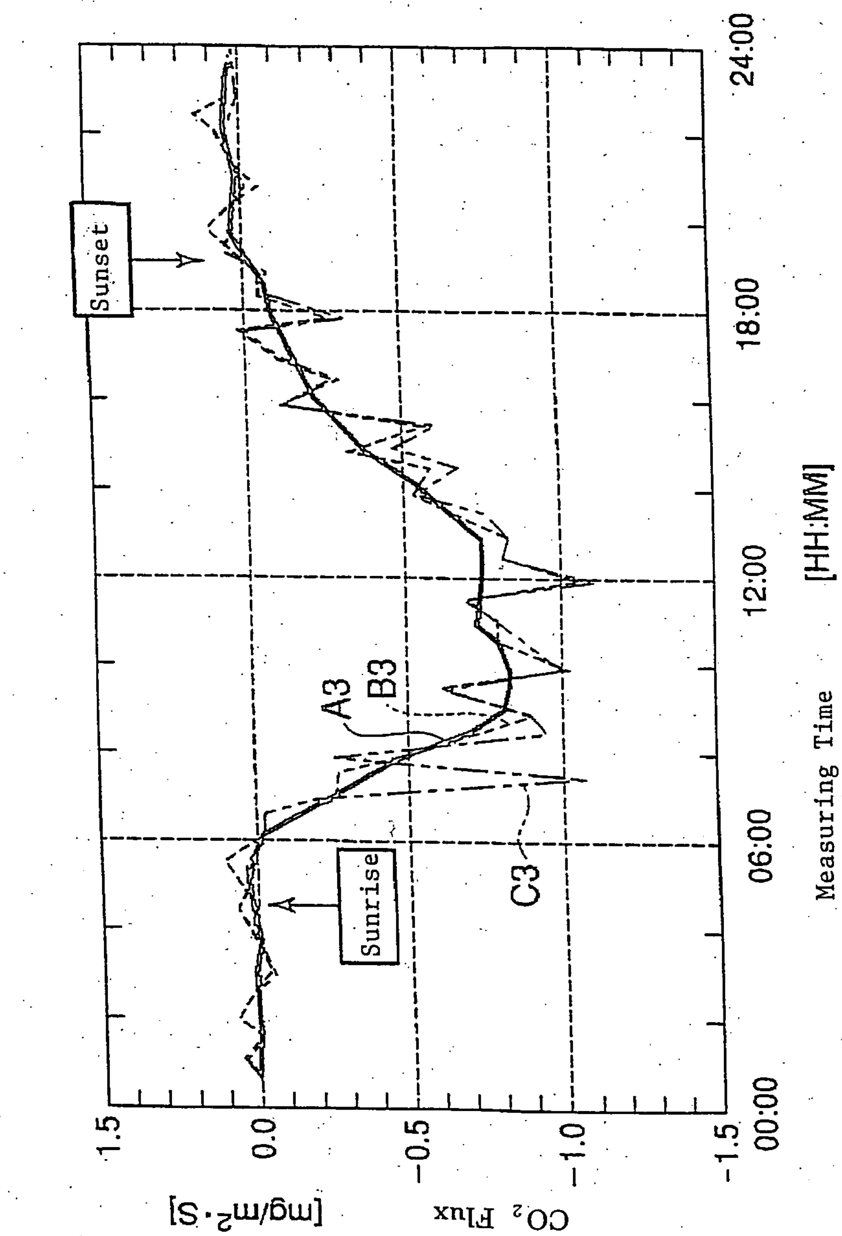
Sunset
Sunrise
A2
C2
B2
1.5
0.0
−0.5
−1.0
−1.5
CO2 Flux
[mg/m2·S]
00:00
06:00
12:00
18:00
24:00
Measuring Time
[HH:MM]

FIG. 9



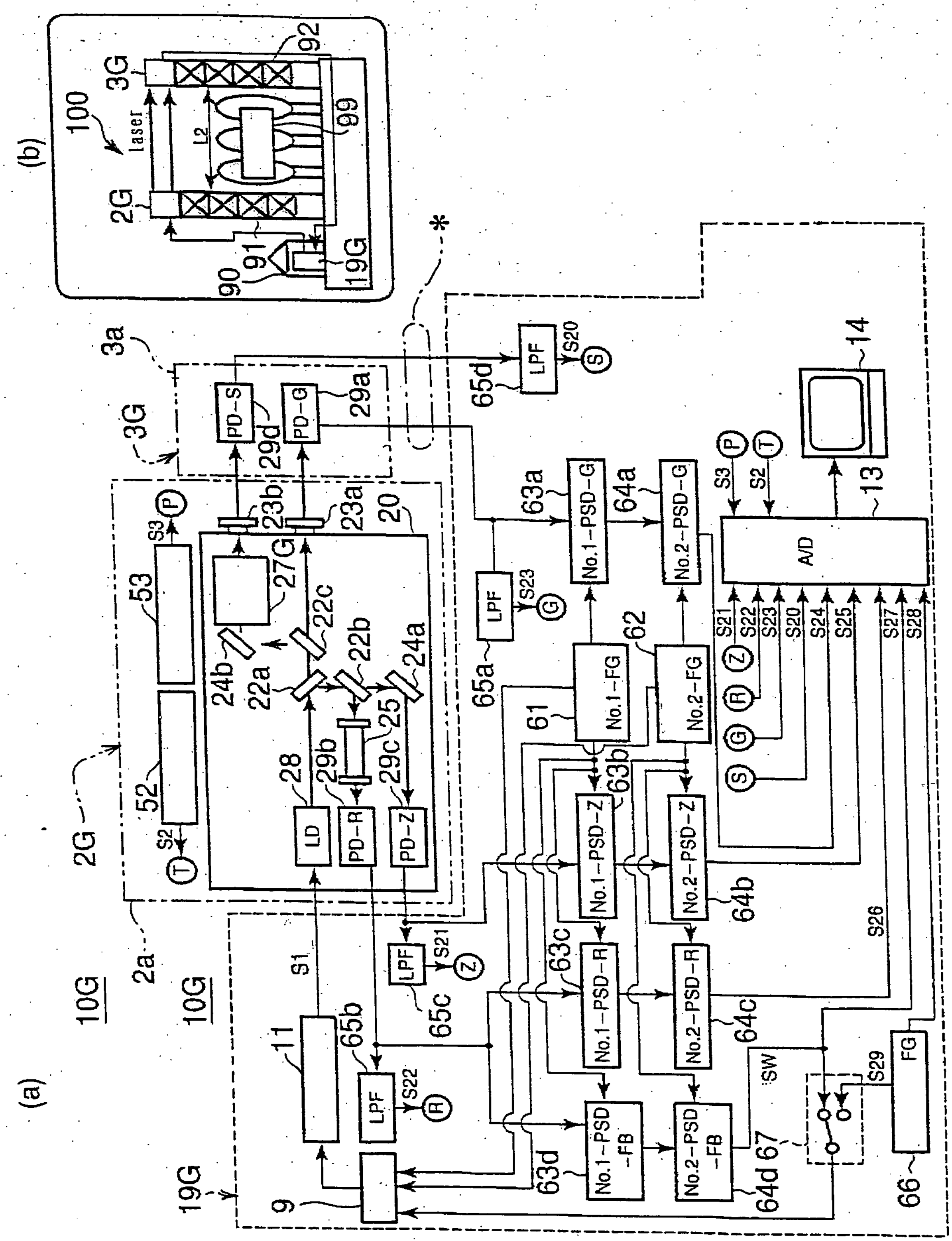
(a)
(b)
10F
100
laser
2F
3F
19F
90
91
92
99
L2
2a
3a
LD1
LD2
PD-R
PD-Z
PD-S
PD-G
LPF
No.1-FG
No.2-FG
No.1-PSD-G
No.2-PSD-G
No.1-PSD-Z
No.2-PSD-Z
No.1-PSD-R
No.2-PSD-R
No.1-PSD -FB
No.2-PSD -FB
FG
A/D
SW
S1a
S1b
S2
S3
S20
S21
S22
S23
S24
S25
S26
S27
S28
S29
9
11a
11b
13
14
20
22a
22b
23a
23b
24
25
28a
28b
29a
29b
29c
29d
52
53
61
62
63a
63b
63c
63d
64a
64b
64c
64d
65a
65b
65c
65d
66
67
*

FIG. 10



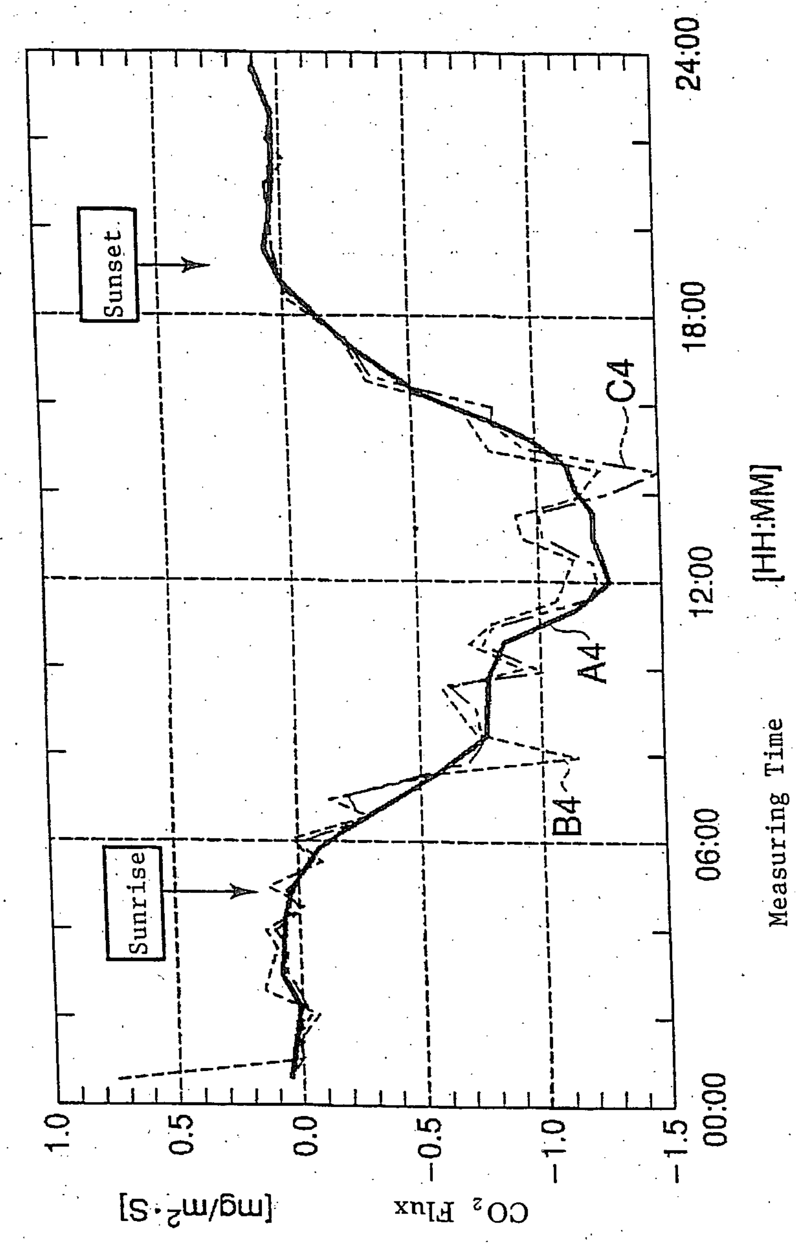
Sunrise
Sunset
A3
B3
C3
1.5
0.0
-0.5
-1.0
-1.5
00:00
06:00
12:00
18:00
24:00
CO_2 Flux
[mg/m²·S]
Measuring Time
[HH:MM]

FIG. 11



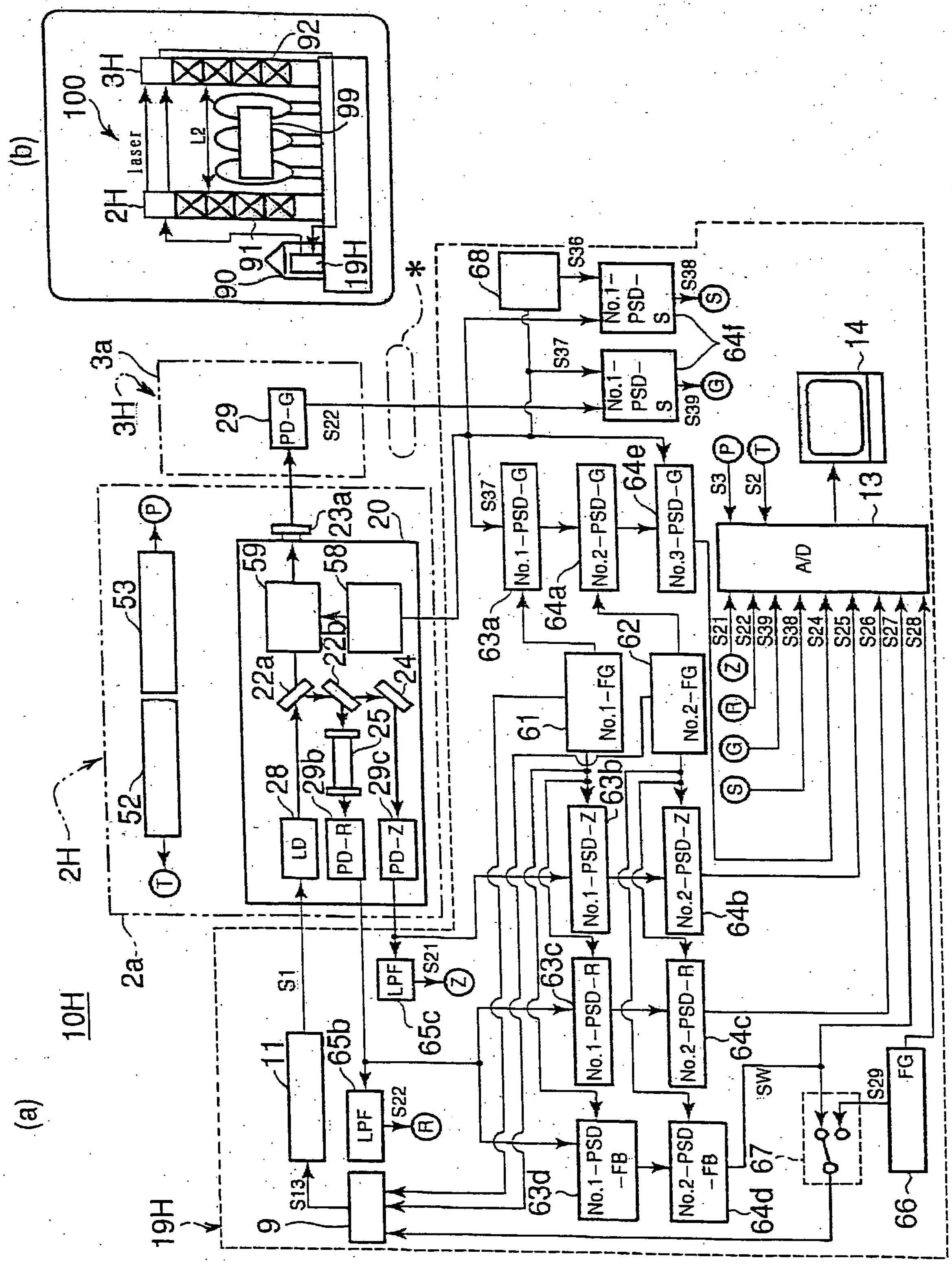
(a)
(b)
100
laser
L2
2G
3G
19G
90
91
92
99
10G
2a
3a
20
23a
23b
27G
22a
22b
22c
24a
24b
25
28
29a
29b
29c
29d
LD
PD-R
PD-Z
PD-S
PD-G
52
53
S1
S2
S3
11
9
65a
65b
65c
65d
LPF
S20
S21
S22
S23
S24
S25
S26
S27
S28
S29
61
62
No.1-FG
No.2-FG
63a
63b
63c
63d
64a
64b
64c
64d
No.1-PSD-G
No.2-PSD-G
No.1-PSD-Z
No.2-PSD-Z
No.1-PSD-R
No.2-PSD-R
No.1-PSD-FB
No.2-PSD-FB
SW
67
66
FG
13
A/D
14
*

FIG. 12



Sunrise
Sunset
A4
B4
C4
1.0
0.5
0.0
-0.5
-1.0
-1.5
CO2 Flux
[mg/m2·S]
00:00
06:00
12:00
18:00
24:00
Measuring Time
[HH:MM]

FIG. 13



(a)
(b)
10H
2a
2H
3H
3a
19H
100
laser
L2
90
91
92
99
2H
3H
19H
52
53
T
P
LD
PD-R
PD-Z
PD-G
28
29
29b
29c
20
22a
22b
23a
24
25
58
59
S1
S13
S21
S22
S2
S3
9
11
65b
65c
LPF
LPF
No.1-FG
No.2-FG
61
62
No.1-PSD-Z
No.2-PSD-Z
No.1-PSD-R
No.2-PSD-R
No.1-PSD-FB
No.2-PSD-FB
No.1-PSD-G
No.2-PSD-G
No.3-PSD-G
No.1-PSD-S
63a
63b
63c
63d
64a
64b
64c
64d
64e
64f
66
67
68
FG
SW
S24
S25
S26
S27
S28
S29
S36
S37
S38
S39
A/D
13
14
*

FIG. 14

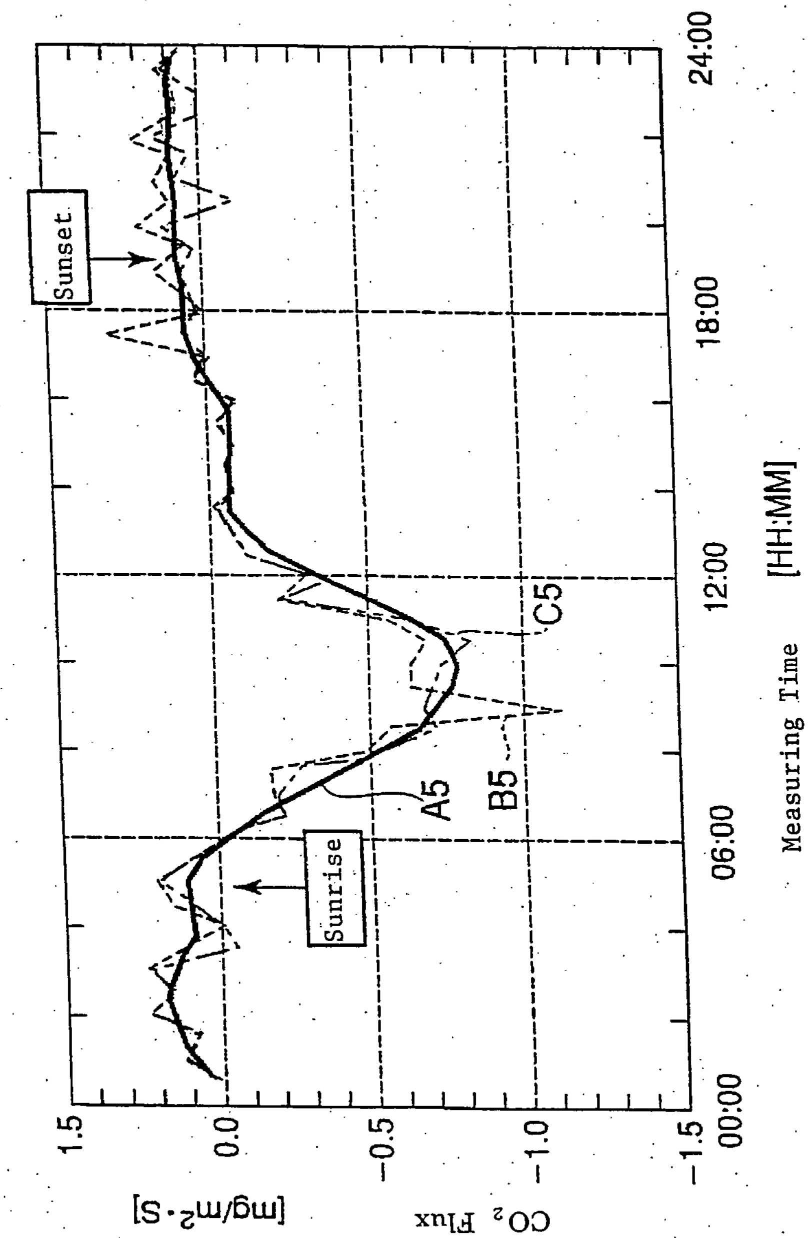

Sunset
Sunrise
A5
B5
C5
1.5
0.0
-0.5
-1.0
-1.5
00:00
06:00
12:00
18:00
24:00
Measuring Time
[HH:MM]
CO_2 Flux
[mg/m²·S]

FIG. 15A (Prior Art)

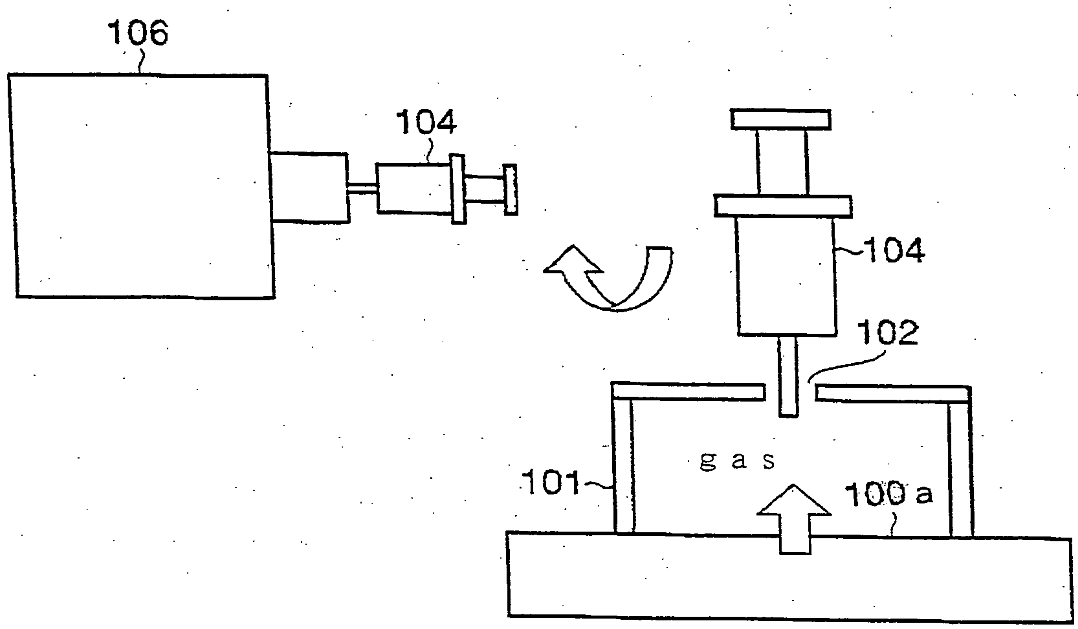


FIG. 15B (Prior Art)

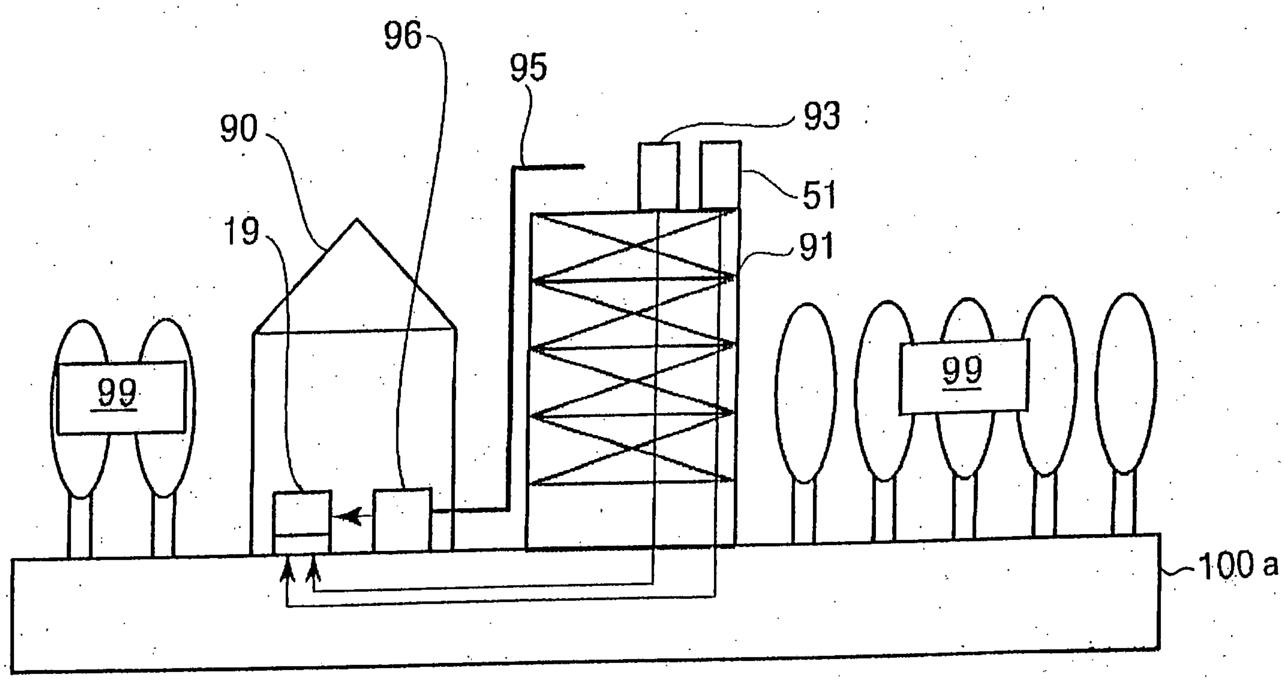


FIG. 15C (Prior Art)

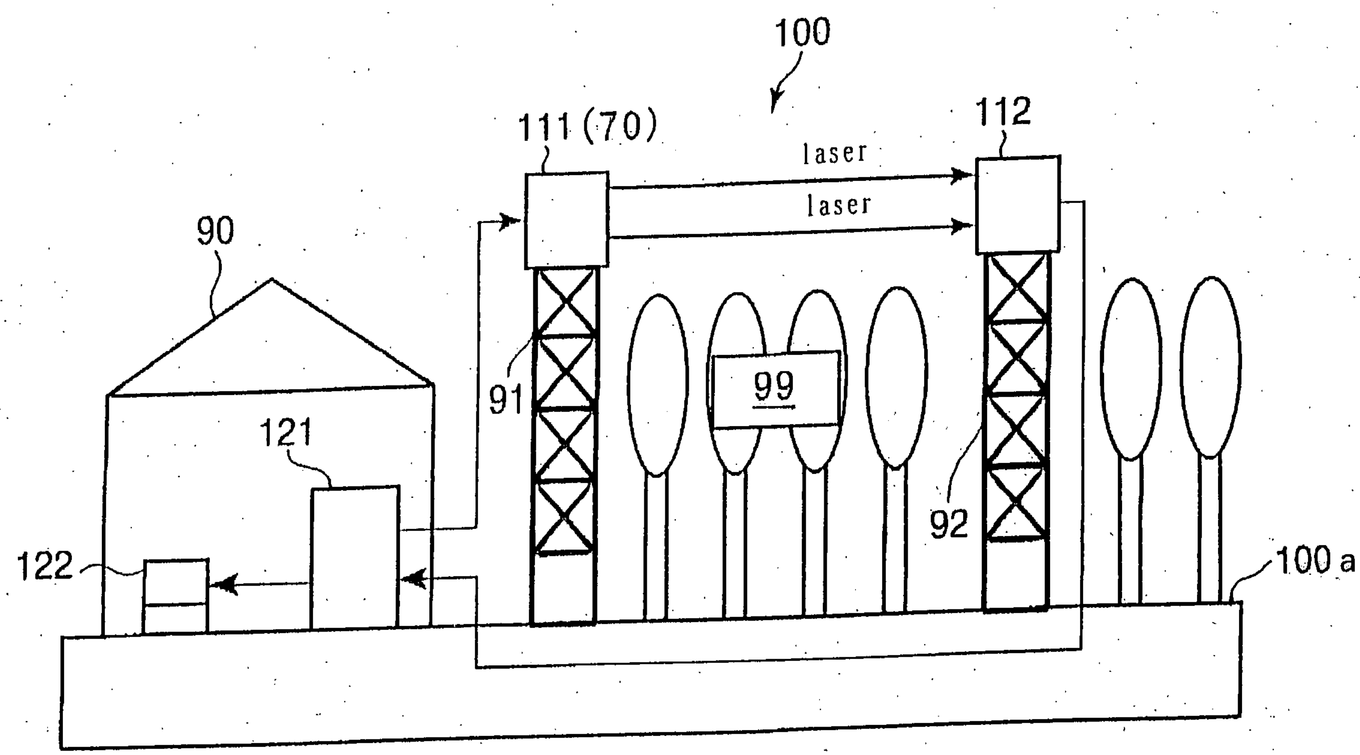


FIG. 15D (Prior Art)

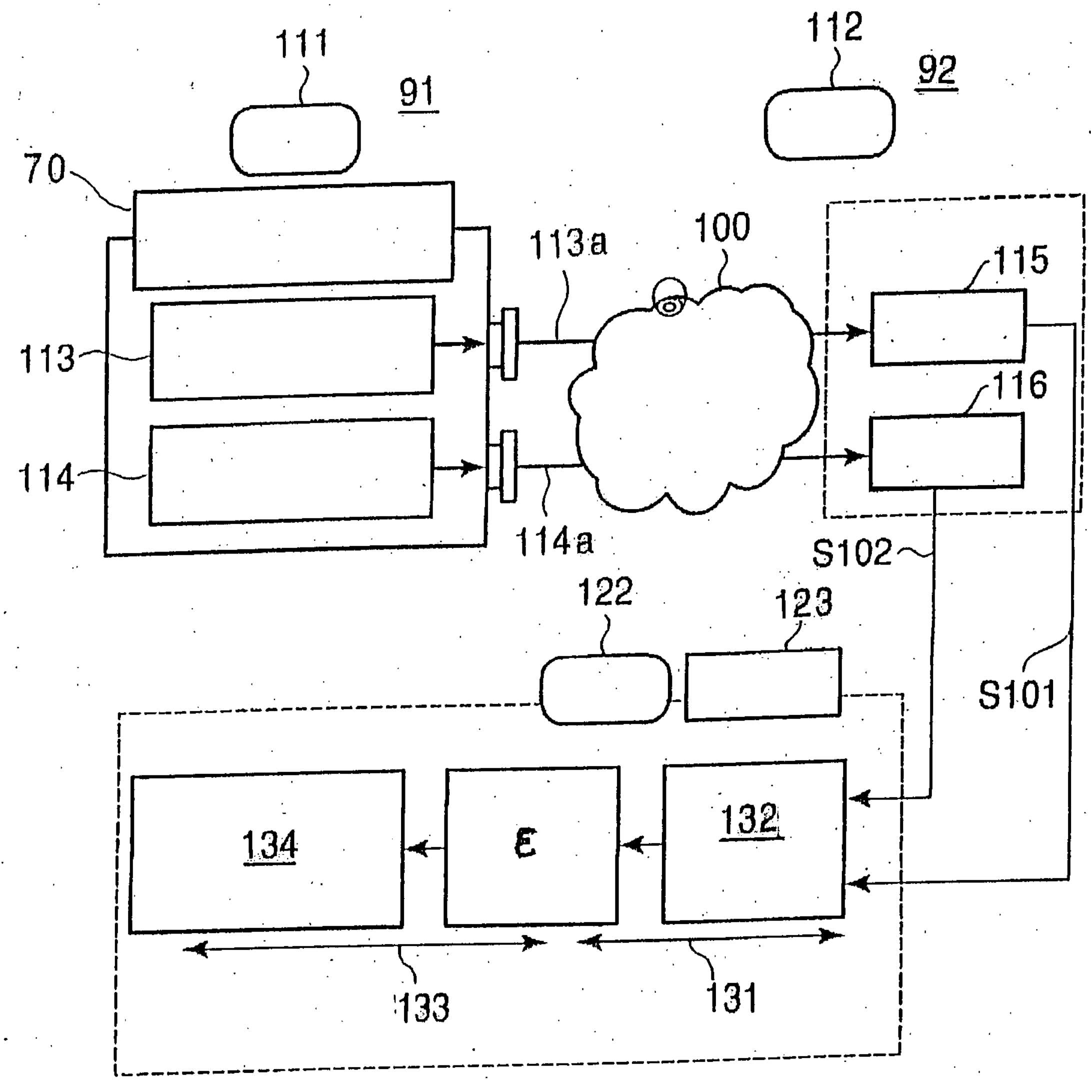


Fig. 16A

Raw data of atmospheric turbulence measurements (observation of atmospheric transmission factor of laser)

Time-wise changes of atmospheric transmission factor of 2 optical path lasers

- B1, B2: Logarithmic variance of laser strength
- B12: Logarithmic covariance of laser strength
- r: Logarithmic correlation coefficient of laser strength

↓

Grasping of atmospheric turbulence state (optical spectrum analysis of atmospheric turbulence state)

Obtaining of internal scale Lo and structure function constant Cn^2 of refractive index changes

$$\left.\begin{array}{l} r=F(Lo, \lambda 1, \lambda 2) \\ B12=aCn^2G(Lo, \lambda 1, \lambda 2) \\ \lambda n: \text{ Laser wavelength, } a: \text{ Constant} \end{array}\right\} \boxed{\text{In case of different laser wavelengths}}$$

$$\left.\begin{array}{l} r=F(Lo) \\ B12=aCn^2G(Lo, d, D) \\ d: \text{ Distance between laser radiating positions,} \\ D: \text{ Diameter of light receiving part} \end{array}\right\} \boxed{\text{In case of the same laser wavelength}}$$

Obtaining of structure function constant of temperature and water vapor changes

$$CN^2=A_T^2/T^2C_T^2+A_q^2/q^2C_q^2+2A_TA_q/TqC_{Tq}$$

$$C_{Tq}=(C_T^2C_q^2)^{1/2} \qquad A_T, A_q: \text{ Constant}$$

Dissipation rate of variance of kinetic energy

$$\varepsilon = \gamma^3(7.4/Lo)^4$$

Dissipation rate of variance of temperature and humidity changes

$$C_T^2=4\beta\,\varepsilon_T\,\varepsilon^{-1/3} \qquad \beta: \text{ Obkhov-Corsin Constant} \qquad C_q^2=4\beta\,\varepsilon_q\,\varepsilon^{-1/3}$$

↓

Obtaining of momentum flux and scalar flux (analysis based on the MOS law)

Fig. 16B

The followings are obtained by repeated calculations based on the MOS law.

(1) MO length $z/L = kgz(H/Cp\ Ta + 0.61E)/[-u*3\rho]$

(2) Friction velocity $u* = [kz\ \varepsilon\ /(\phi_{\varepsilon}(z/L)]^{1/3}$

(3) Sensible heat flux $H = \rho Cp[kzu*\ \varepsilon_{T}/\ \phi_{\varepsilon T}(z/L)]^{1/2}$

(4) Latent heat flux $LE = \rho L[kzu*\ \varepsilon_{q}/\ \phi_{\varepsilon q}(z/L)]^{1/2}$

z : Measuring height, k : Karman Constant, g : Gravitational acceleration,

Cp : Constant pressure specific heat of air, ρ : Air density

$\phi n(z/L)$: Monin-Obukhov universal function ($n = \varepsilon, \varepsilon_{T1}\ \varepsilon q$)

Momentum Flux=$\rho\overline{u^{1}w^{1}}$

Sensible heat flux=$\rho cp\overline{T^{1}w^{1}}$

Water vapor flux=$\rho\overline{Lq^{1}w^{1}}$

Fig. 17A

1. Turbulence state measurements

Grasping of atmospheric turbulence state

(1) Scintillation measurements of laser

(2) Calculation of statistical quantity (variance, covariance) using measured values

Analysis of atmospheric turbulence state

(1) Calculation of internal scale Lo

(2) Lo→Turbulence energy dissipation rate ε

(3) Structure function parameter of density: Calculation of Cn^2

2. Atmospheric gas concentration measurements

Grasping of gas concentration

$$\text{Gas concentration} = \frac{\left(\dfrac{\text{Atmospheric side laser absorption quantity}}{\text{Atmospheric side laser received light strength}}\right)}{\left(\dfrac{\text{Reference cell laser absorption quantity}}{\text{Reference cell laser received light strength}}\right)}$$

Turbulence analysis of gas concentration

(1) Fourier transform of measured values (t: time→r: eddy scale)

(2) C_g^2 calculation by structure function analysis of gas concentration

$D_{gg}(r)=[G(x+r)-G(x)]^2=C_g^2\cdot r^{2/3}$

(3) Calculation of dissipation rate ε_g of concentration $\varepsilon_g=C_g^2/f_g(\varepsilon)$

3. Air temperature measurements

Grasping of air temperature

For example:

① Thermocouple

② 2 wavelength laser measurement (2 color method)

③ Absorption spectrum analysis, etc.

Turbulence analysis of air temperature

(1) Fourier transform of measured values (t: time→r: eddy scale)

(2) C_T^2 calculation by structure function analysis of temperature

$D_{TT}(r)=[T(x+r)-T(x)]^2=C_T^2\cdot r^{2/3}$

(3) Calculation of dissipation rate ε_T of temperature

$\varepsilon_T=C_T^2/f_T(\varepsilon)$

Grasping of influence of latent heat flux by relations of each structure function

(1) Calculation of humidity structure function parameter C_q by relations of each structure function C_n, C_T, C_g

$$Cn^2=\left[\frac{A_T^2}{\bar{T}^2}\cdot C_T^2+\frac{A_Q^2}{\bar{Q}^2}\cdot C_q^2+\frac{A_G^2}{\bar{G}^2}\cdot C_g^2+2\cdot\frac{A_T\cdot A_Q}{\bar{T}\cdot\bar{Q}}\cdot C_T\cdot C_Q+2\cdot\frac{A_T\cdot A_Q}{\bar{T}\cdot\bar{G}}\cdot C_T\cdot C_g+2\cdot\frac{A_Q\cdot A_G}{\bar{Q}\cdot\bar{G}}\cdot C_Q\cdot C_g\right]$$

$\bar{\ }$: Average value of each physical quantity

A : Constant of each physical quantity [$\propto f(P, \lambda)$]

P: air pressure λ: measurement laser wavelength

Fig. 17B

(2) Calculation of dissipation rate ε_q of temperature

$$\varepsilon_q = C_q^2 / f_q(\varepsilon)$$

Analysis based on MOS law

① L: Obukhov length: $\frac{z}{L} = \frac{k_v \cdot g \cdot z \cdot T_*}{u_*^2 \cdot T}$

② u_*: Friction velocity$= \overline{(-u^1 \cdot w^1)^{1/2}} = \frac{k_v \cdot z \cdot e}{f_u = (z/L)}$

③ T_*: Friction temperature$= \overline{(w^1 \cdot T^1)} = \frac{k_v \cdot z \cdot e_T}{f_T = (z/L)}$

④ Q_*: Friction specific humidity$= \overline{(w^1 \cdot Q^1)} = \frac{k_v \cdot z \cdot e_q}{f_q = (z/L)}$

⑤ G_*: Friction specific concentration$= \overline{(w^1 \cdot G^1)} = \frac{k_v \cdot z \cdot e_g}{f_g = (z/L)}$

- ·z: Measuring length
- ·k_v: von Karman Constant
- ·g: Gravitational constant

(1) Gas flux: $G = \rho \cdot u_* \cdot G_*$

(2) Momentum flux: $M = \rho \cdot u_*^2$

(3) Sensible heat flux: $H = Cp \cdot \rho \cdot u_* \cdot T_*$

(4) Latent heat flux: $E = L_\theta \cdot \rho \cdot u_* \cdot Q_*$

- ·ρ: Air density
- ·Cp: Air constant pressure specific heat
- ·L_θ: Latent heat